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**THE DEVELOPMENT OF BEARING CAPACITY
DESIGN CHARTS FOR TRACK SYSTEMS**

SUMMARY REPORT

Prepared for

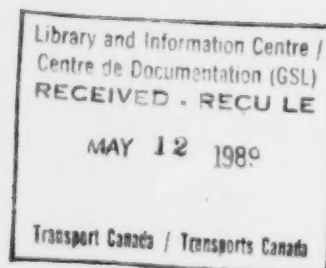
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16. Abstract The objective of this study is to present a bearing capacity type design procedure for assessing the stability of the track subgrades. A previous research program emphasized the measurement of the matric suction in the subgrade of a track structure. The current phase of the research program concentrated on the incorporation of the matric suction term into a bearing capacity design procedure. This permits the design procedure to utilize the additional strength of the soil resulting from matric suction. Design charts have been developed for various train loads, subballast thicknesses, soil types, and design matric suction values. The design charts give a factor of safety against bearing capacity failure as a function of the above parameters. Stresses in the subgrade are predicted utilizing the computer program GEOTRACK for various design train loads, subballast thicknesses, and soil parameters. The allowable stress, or bearing capacity, is determined using bearing capacity theories modified to accommodate the layered track system and also incorporate the additional strength of the soil resulting from matric suction. A comparison of predicted stresses and bearing capacity defines the factor of safety against a bearing capacity failure.					
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16. Résumé La recherche avait pour objet l'étude d'une méthode de calcul de la stabilité d'une plate-forme ferroviaire tenant compte de la portance des sols supports. Des recherches antérieures avaient débouché sur des méthodes permettant de mesurer la succion capillaire d'un sol. La présente recherche visait à élaborer une méthode de calcul de la portance qui considère ce nouvel élément qu'est la succion, de manière à pouvoir en tirer tout le parti possible. Des courbes de calcul ont pu ainsi être développées prenant en compte des valeurs types de charges à l'essieu, d'épaisseur de la sous-couche, de classes de sols et diverses valeurs de référence de succion. On en tire un facteur de sécurité, fonction de ces paramètres, protégeant contre le risque d'un dépassement de la portance susceptible d'entraîner la ruine de la plate-forme. Les contraintes théoriques engendrées dans la plate-forme peuvent être calculées à l'aide d'un programme informatique appelé GEOTRACK, au regard des charges à l'essieu, de l'épaisseur de la sous-couche et des caractéristiques mécaniques du sol. La contrainte admissible, ou portance, peut être déterminée en s'appuyant sur les théories reconnues, modifiées pour tenir compte de la caractéristique multicouche d'une voie ferrée et auxquelles a été ajouté l'élément de succion ainsi que l'excédent de force qu'elle autorise. En comparant la portance théorique d'un sol à la courbe de distribution des contraintes s'exerçant sur ce sol, il est possible d'obtenir un ordre de grandeur de la marge de sécurité disponible contre le dépassement de la portance du sol support.				
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EXECUTIVE SUMMARY

In 1982, Professor D.G. Fredlund of the Geotechnical Group at the University of Saskatchewan, Saskatoon, Saskatchewan proposed a four-stage research program to develop a better understanding of the role played by soil suction in the behaviour and design of track system subgrades. Earlier work, now completed, was undertaken jointly with Clifton Associates Ltd., Regina, Saskatchewan and was devoted to an investigation of suitable methods for measuring soil suction in the field. Having developed suitable procedures for measuring soil suction, the objective of the present phase of research was to incorporate the soil suction term into a workable design procedure. This permits the design procedure to utilize the additional strength of the soil resulting from the suction in the subgrade.

A bearing capacity design procedure for the railway-ballast-subballast-subgrade system was developed in which the strength of the unsaturated soil is related to the stress state, material parameters, soil suction and failure geometry.

The stresses beneath the loaded track system are computed from a computer program called **GEOTRACK**, which combines the stiffness matrix of the tie-track system with a Boussinesq stress distribution in the ballast-subballast-subgrade system. Stresses are predicted for various train loads, subballast thicknesses and soil parameters.

A comparison of the subgrade system bearing capacity and the subgrade system stress distribution provides a measure of the factor of safety against a bearing capacity type failure. Design charts have been developed for typical design train loads, subballast thicknesses, soil

types, and design soil suction values. The user may choose to use the design charts or the user may choose to use the series of computer programs which were developed to compute the factor of safety against bearing capacity failure.

Present research indicates that a bearing capacity factor of safety of 2.5 to 3.0 would be reasonable for use with the design charts presented for railway systems. However, further research is required to develop confidence in the use of a particular factor of safety for the bearing capacity computation.

The bearing capacity design procedure should be used to complement existing design procedures. It is only through use that the design procedure can be assessed for approval or modification. Use of the procedure will provide feedback on an appropriate bearing capacity factor of safety for design, information on the reliability of the stress calculations, and the reliability of the soil suction parameters.

SOMMAIRE

En 1982, le professeur D.G. Fredlund du groupe géotechnique de l'Université de la Saskatchewan à Saskatoon, avait proposé le lancement d'un programme de recherche en quatre étapes ayant pour but d'approfondir l'influence de la succion capillaire sur le comportement des sols supports de voies ferrées et, partant, sur la conception de celles-ci. La phase 1 des travaux, entreprise conjointement avec Clifton Associates Ltd. de Regina (Saskatchewan), a porté exclusivement sur l'étude de méthodes permettant de mesurer la succion in situ. La recherche ayant abouti, les travaux actuels visent à intégrer l'élément que constitue la succion dans une méthode de calcul facile d'exploitation, dont l'objet est de tirer parti de l'excédent de résistance du sol conférée par cette force de succion.

C'est ainsi qu'a pu être élaborée une méthode de calcul de la portance concernant un système multicouches voie ferrée/ballast/sous-couche/plate-forme où la portance du sol support est exprimée en fonction des états de contraintes, des caractéristiques granulométriques et de la géométrie de rupture.

Les contraintes dans le sol support résultant de l'effet d'une charge en surface, en l'occurrence le système précité, peuvent être calculées grâce à un programme informatisé appelé **GEOTRACK**. Ce dernier combine la matrice de raideur du système traverse-rail à une distribution de contraintes type Boussinesq s'exerçant sur le système ballast/sous-couche/plate-forme. On obtient ainsi des courbes de contraintes en fonction des charges à l'essieu, de l'épaisseur de la sous-couche et des caractéristiques mécaniques du sol support.

En comparant la portance d'un sol à la courbe de distribution des contraintes qui s'exercent sur ce sol, il est possible de tirer un ordre de grandeur de la marge de sécurité disponible contre le dépassement de la portance du sol support. Des courbes de calcul ont été développées prenant en compte des valeurs types de charges à l'essieu, d'épaisseur de la sous-couche, de classes de sols et diverses valeurs de référence de succion. Pour calculer le facteur de sécurité, l'utilisateur a le choix entre ces courbes de calcul et une série de programmes informatiques élaborés à cette fin.

Dans l'état actuel de la recherche, un facteur de sécurité entre 2,5 et 3 semble raisonnable dans le contexte ferroviaire nous concernant. Cependant, des recherches plus poussées seront nécessaires en vue de confirmer la confiance que l'on pourrait avoir à l'égard d'un facteur de sécurité de telle ou telle valeur particulière.

Il est recommandé d'utiliser la méthode de calcul de la portance parallèlement aux méthodes courantes, de manière à mettre sa validité à l'épreuve et à déterminer si une mise au point s'avère nécessaire, avant son adoption définitive. De cette façon, on pourra déterminer le facteur de sécurité approprié en ce qui a trait à la portance, la fiabilité des calculs des contraintes et la justesse de l'appréciation des effets des paramètres de succion.

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1.0 INTRODUCTION

In 1982, the Geotechnical Group at the University of Saskatchewan, Saskatoon, Saskatchewan, under the direction of D.G. Fredlund, proposed a four-stage research program to Canadian Pacific Railways, Canadian National Railways, and the Transportation Development Centre. The object of the program was to develop a better understanding of the role played by soil suction in the behaviour and design of track system subgrades. An earlier research program, conducted by Clifton Associates Ltd., Regina, Saskatchewan, in cooperation with the University of Saskatchewan, was devoted to an investigation of suitable methods for measuring soil suction in the field and the collection of soil suction data on a continuing basis from five field sites in western Canada.

The second stage proposal, submitted in February 1987 on behalf of the Geotechnical Group, University of Saskatchewan, was approved in October 1987. Work commenced on the contract in November 1987.

This stage of the program addressed the effect of soil suction on the design of the subgrade of the track structure. Soil suction is defined as negative pore-water pressure referenced to the pore-air pressure. The pore-water pressure above the ground-water table is generally negative and when referenced to the pore-air pressure becomes a variable which varies in response to the surrounding microclimate. Figure 1 illustrates typical negative pore-water pressure profiles in the upper layers of a track-subgrade system.

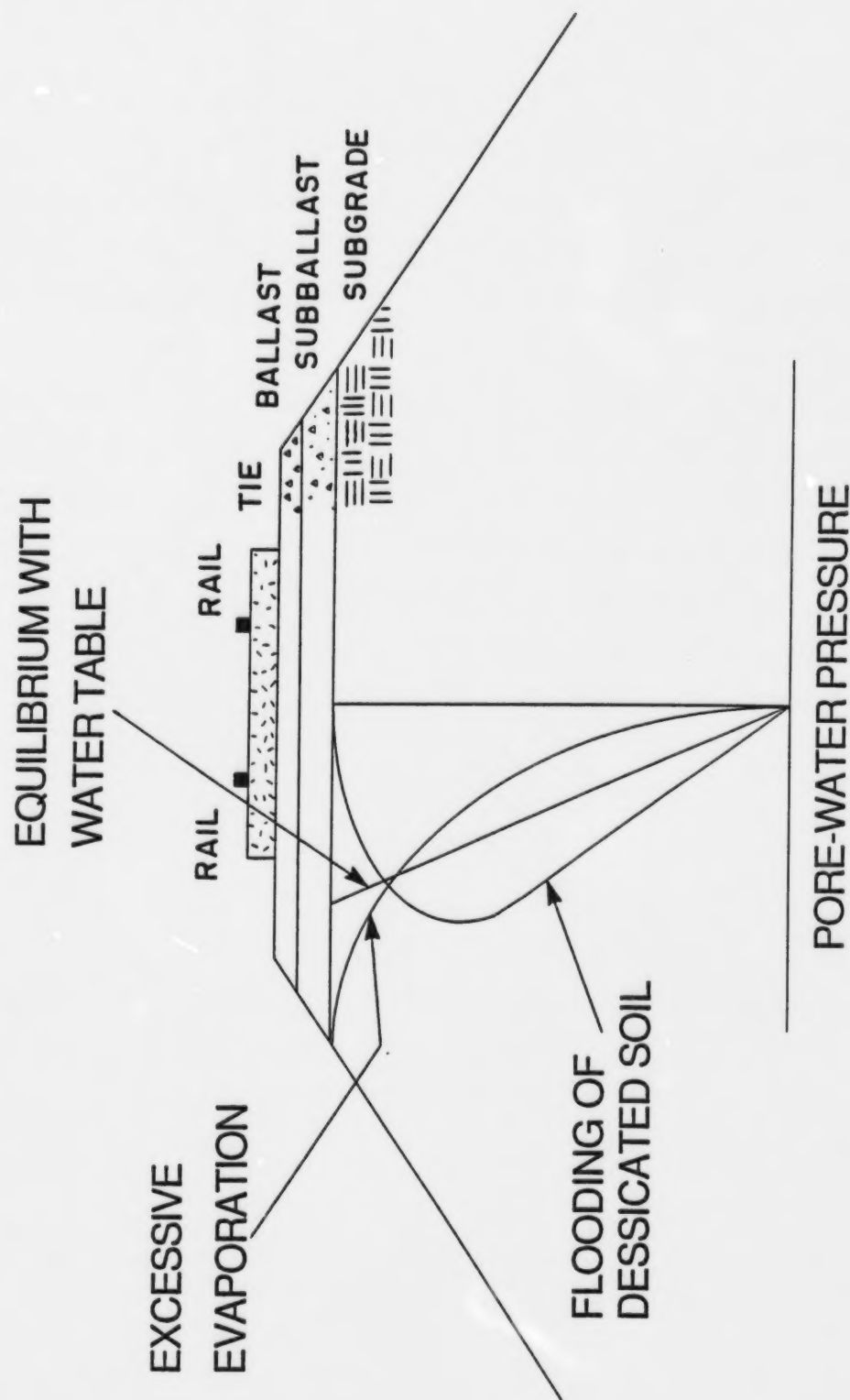


Fig. 1 Idealized pore-water pressure profiles beneath a railroad track

2.0 OBJECTIVE

The second stage of research concentrates on the incorporation of the soil suction term into a workable design procedure. The objective of the most recent research was to develop a bearing capacity design procedure for the railway-ballast-subballast-subgrade system, incorporating soil suction into the design procedure. An understanding of the role of soil suction permits the design procedure to utilize the additional strength of the soil resulting from soil suction.

3.0 SCOPE

The design procedure which has been developed utilizes a bearing capacity approach in which the strength of the unsaturated soil is related to the stress state variables, material parameters, soil suction and failure geometry. Two methods are used for the estimation of the bearing capacity beneath a loaded track structure. The Meyerhof and Hanna (1) approach applies only to weak clay subgrades, whereas the Broms (3) approach applies to stronger clays, glacial tills, silt and sand subgrades. The soil suction term is incorporated into both procedures.

An overall view of the tie-track-ballast-subballast-subgrade system is shown in Figure 2. Four geometries for bearing capacity failure are considered. These include: Option 1) a geometry perpendicular to the track for the entire track (Figure 3), Option 2) a geometry perpendicular to the track for double truck loading (Figure 4), Option 3) a geometry parallel to the track for an individual tie (Figure 5), and Option 4) a geometry parallel to the track for double truck loading (Figure 6).

The subgrade stress occurring at the subgrade surface immediately beneath the loaded tie-track system is calculated using the computer

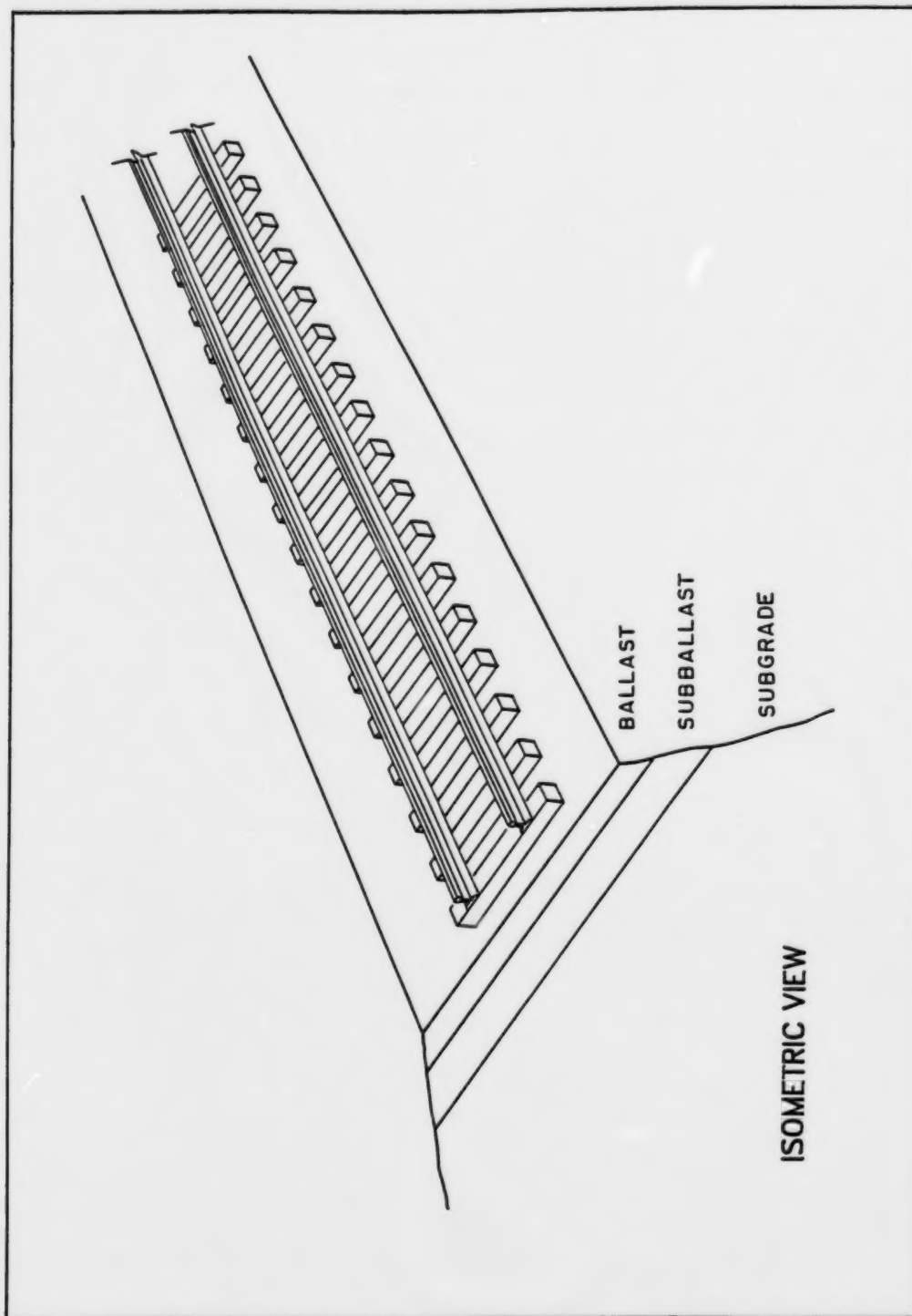


Fig. 2 An overall view of the tie-track-ballast-subballast-subgrade system

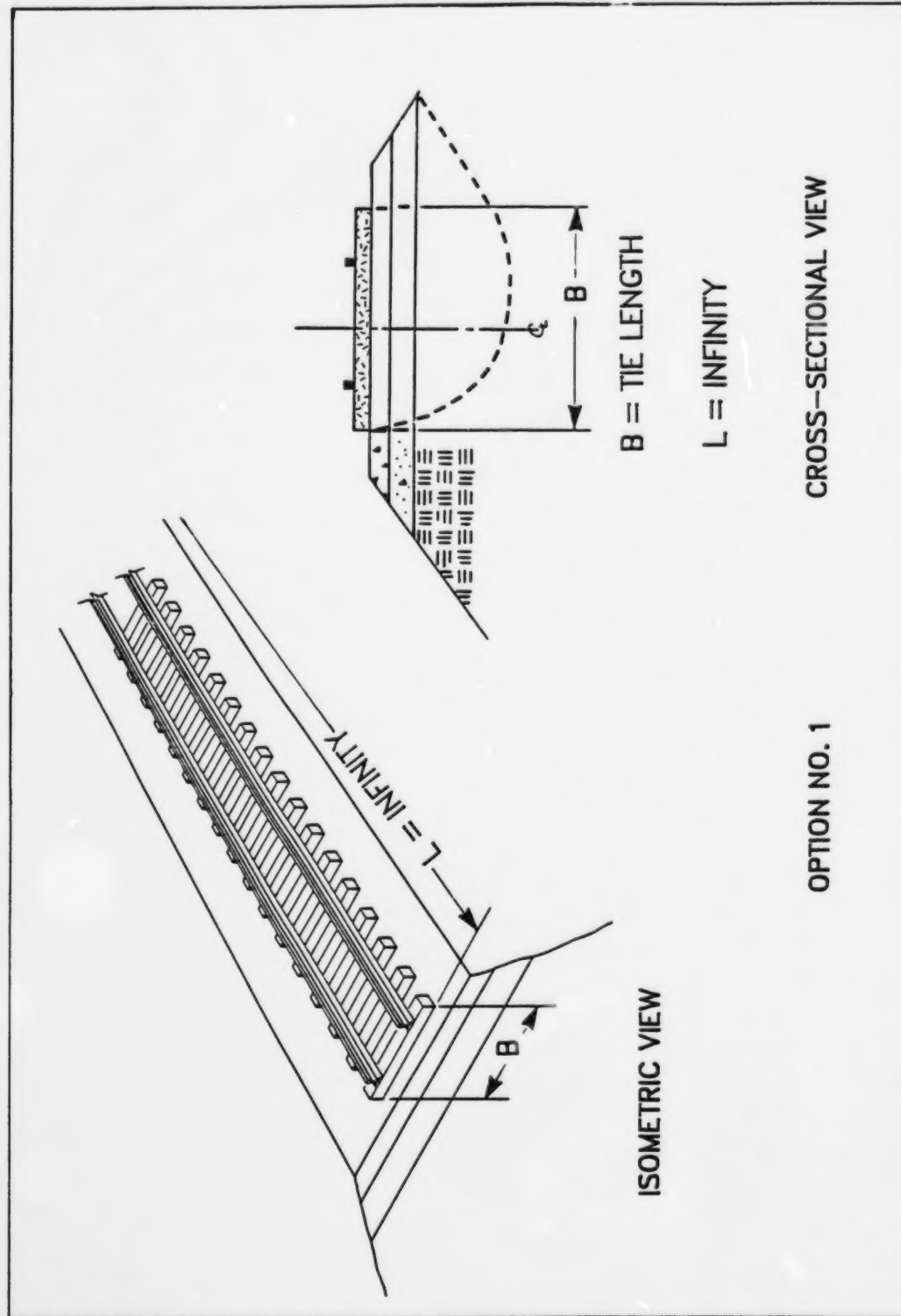


Fig. 3 Option 1: Geometry of a bearing capacity failure perpendicular to the track for double truck loading

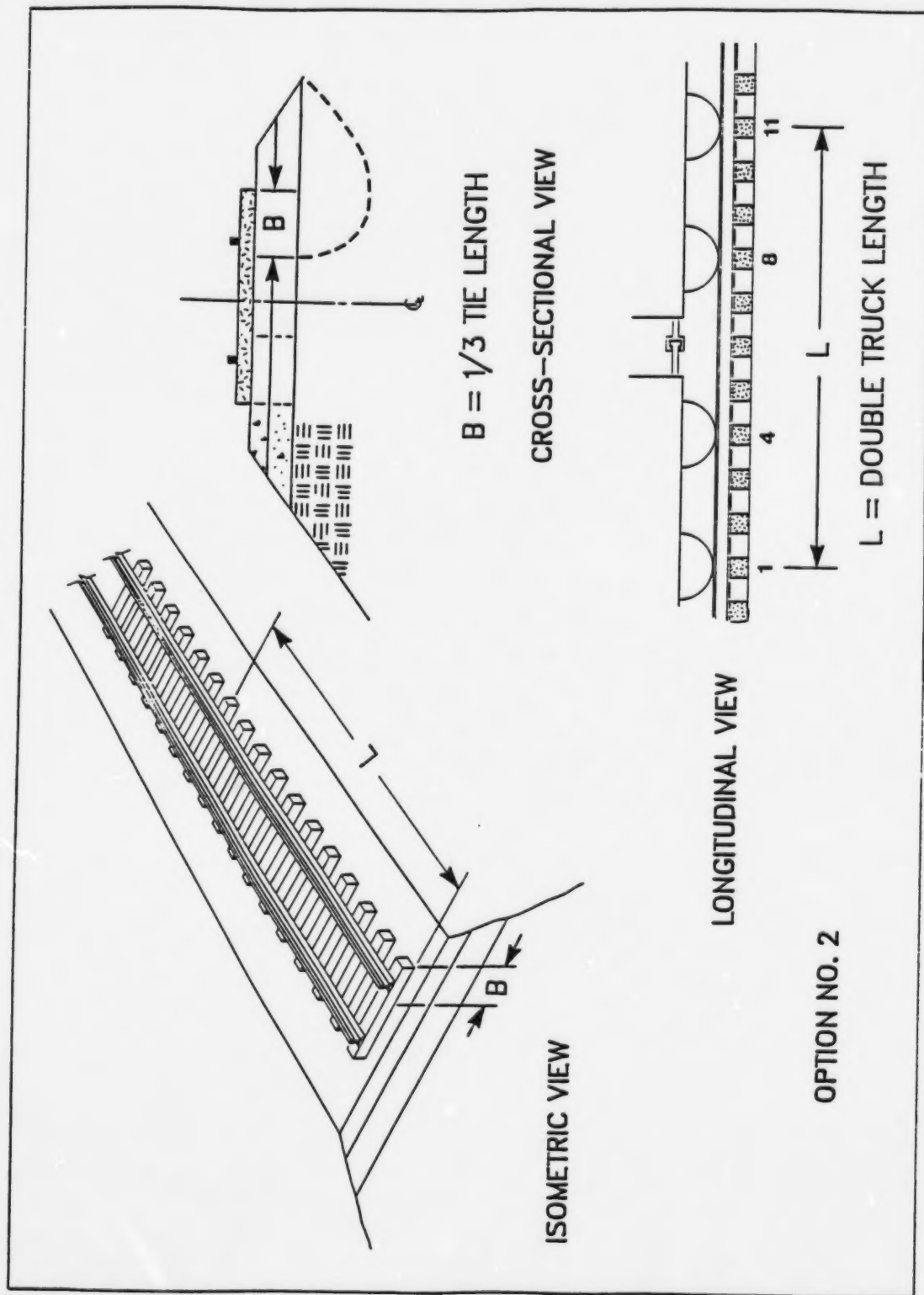


Fig. 4 Option 2: Geometry of a bearing capacity failure perpendicular to the track for the entire track

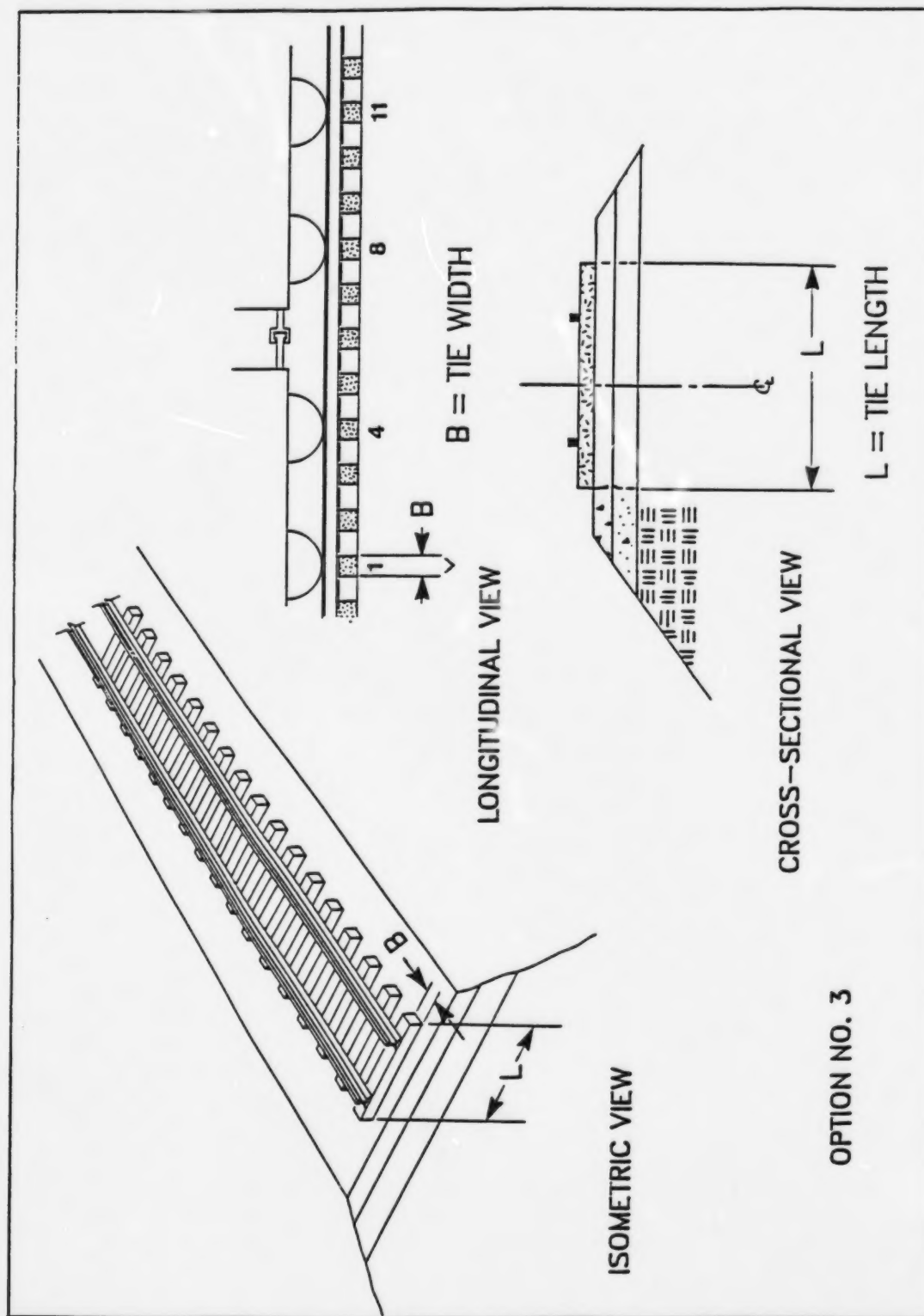


Fig. 5 Option 3: Geometry of a bearing capacity failure parallel to the track for an individual tie

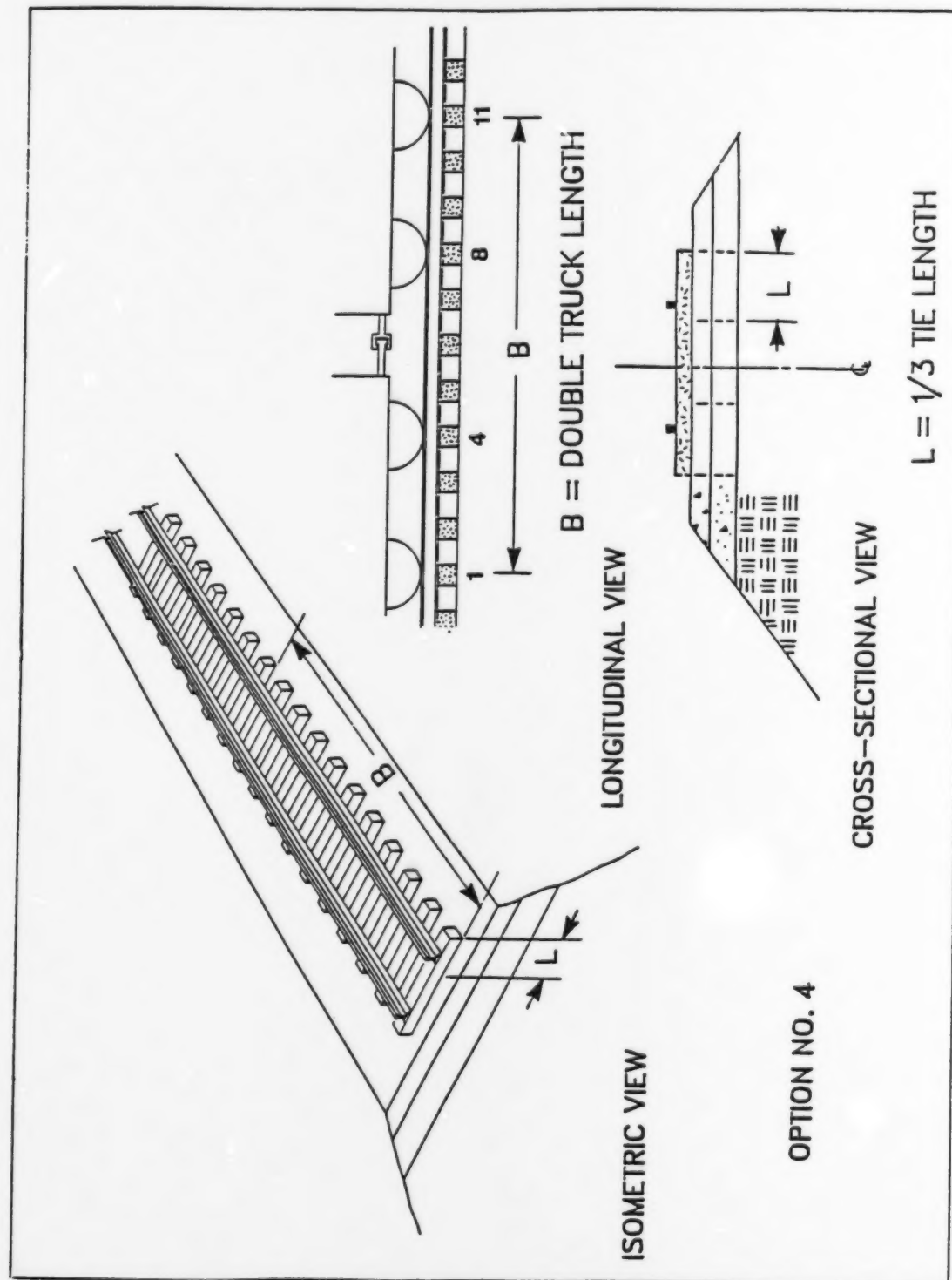


Fig. 6 Option 4: Geometry of a bearing capacity failure parallel to the track for double truck loading

program, called GEOTRACK, which relates the stiffness matrix of the tie-track system to a Boussinesq stress distribution in the ballast-subballast-subgrade layered soil system.

Design charts for bearing capacity factor of safety have been developed by comparing the estimated bearing capacity to a computed average stress at the subgrade surface. The various design charts are presented as a function of the failure geometry, the subballast and subgrade repeated loading moduli, the axle loads as well as reasonable bearing capacities for typical western Canadian soils.

4.0 METHODOLOGY

The design charts arise from a comparison of a computed stress within the tie-track system to the estimation of the bearing capacity of the layered soil system. This section presents the approach to estimating bearing capacity and the approach to computing an average stress from the GEOTRACK computer program. The comparison of the bearing capacity value and the average stress are presented in a discussion of the bearing capacity charts.

4.1 Ultimate Bearing Capacity

Two methods have been considered for the estimation of the bearing capacity beneath a loaded tie-track structure.

4.1.1 Hanna and Meyerhof Approach to Bearing Capacity

The approach introduced by Hanna and Meyerhof in 1980 (1) assumes a failure mechanism in which the upper dense sand layers are pushed into the lower clay layer (Figure 7). This mechanism of

failure is reasonable for a tie punching into the subgrade and has been known to occur when the subballast layer is absent and the subgrade is a soft clay. Kraft and Helfrich (2) suggest that the Hanna and Meyerhof approach to computing bearing capacity is satisfactory for shallow footings on weak deposits.

Figure 7 illustrates the failure mechanism assumed by Hanna and Meyerhof (1980). At the point of limiting equilibrium, the sum of the forces in the vertical direction yields an equation for the ultimate bearing capacity. Laboratory data collected by Hanna and Meyerhof give rise to an appropriate equation for the passive earth resistance based upon an assumed coefficient of punching shear (1). The resulting bearing capacity equation is

$$q_u = cN_c + \gamma_1 H^2 (1 + 2D/H) K_s \tan \phi' / B - \gamma_1 H \quad [1]$$

where:

c = undrained shear strength of the soft clay subgrade

N_c = bearing capacity factor

γ_1 = unit weight of overlying dense sand (ballast)

H = thickness of dense sand below the bottom of the footing (or railway tie)

D = depth of embedment of the footing (or railway tie)

K_s = coefficient of punching shear resistance (determined from published charts)

ϕ' = friction angle of the upper dense sand (or ballast), and

B = width of the footing (or railway tie)

The soil suction term can be incorporated into the Hanna and Meyerhof equation by replacing the undrained shear strength of the clay with the more rigorous c' and ϕ' terms as illustrated below:

$$c = c' + (u_a - u_w) \tan \phi' \quad [2]$$

where:

- c' = the effective cohesion of the subgrade
- $(u_a - u_w)$ = design suction value for the subgrade
- ϕ^b = rate of change in shear strength with respect to soil suction

Equation [2] is shown in diagram form in Figure 8.

4.1.2 Broms Approach to Bearing Capacity

Broms approach (3) to computing bearing capacity is illustrated in Figure 9. The granular material distributes the applied load to an enlarged area, such that the stress at the subgrade surface is smaller in magnitude than the stress immediately beneath the footing. The conventional bearing capacity equation may be used to represent the subgrade bearing capacity, taking into consideration the decreased stress at the subgrade surface (i.e., caused by the distribution of the applied stress through the granular layers).

The approach adopted in the final report uses the conventional bearing capacity equation with the actual dimensions of the footing (or tie-track system). The bearing capacity computed in this manner

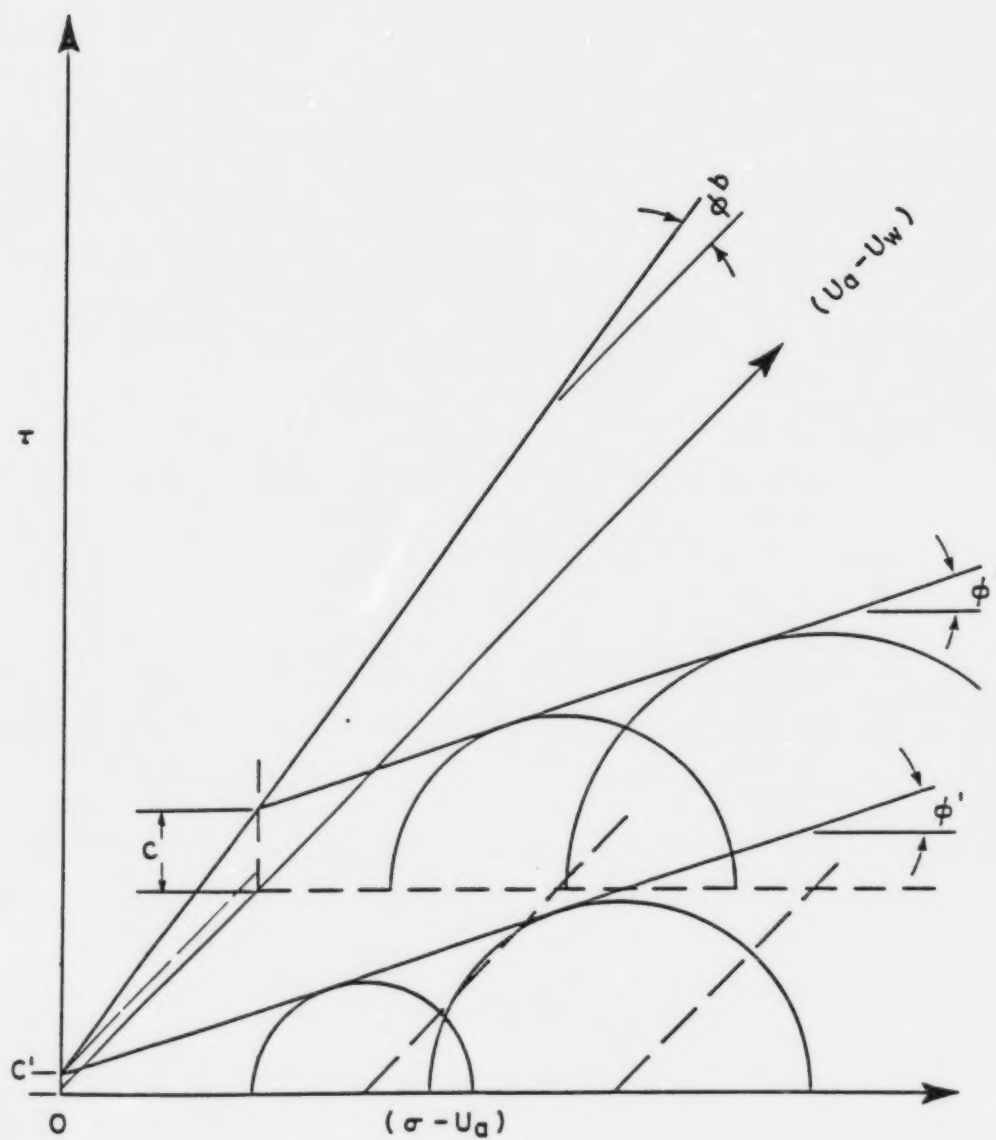


Fig. 8 The components of the total cohesion

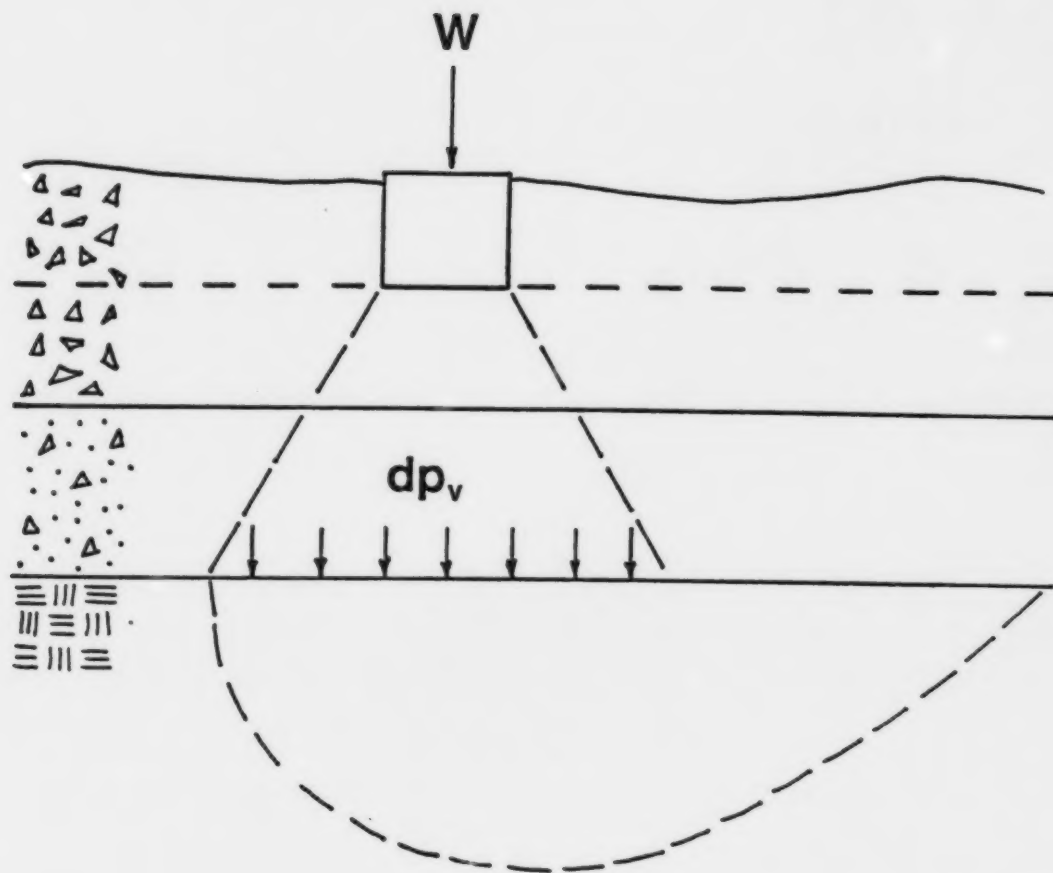


Fig. 9 Broms approach to computation of subgrade bearing capacity

is then compared to the stress which reaches the subgrade surface through the granular material from the applied load (i.e., the subgrade surface stress modelled by the computer program, GEOTRACK).

Broms (3) took a slightly different approach to computing the subgrade bearing capacity. Since there was no reliable method available to compute the stress at the subgrade surface, Broms used the applied load over an enlarged area to represent the decreased stresses which reach the subgrade surface through the granular material.

When the rail-tie system is considered as a contiguous unit placed upon the ballast-subballast-subgrade system, the Broms approach provides a reasonable estimate of the general bearing capacity failures which occur under field conditions. The advantage of Broms method over the Hanna and Meyerhof method is that the Broms approach can be applied to a broader spectrum of soil types, failure geometries and loading conditions.

The equation for bearing capacity bears the same form as the conventional bearing capacity equation:

$$q_u = cN_c + 0.5\gamma BN_\gamma + q_o N_q \quad [3]$$

where:

N_c, N_γ, N_q = bearing capacity factors

c = total cohesion or undrained shear strength

γ = unit weight of the overlying ballast and subballast material

B = width of the footing (or railway bearing area, depending

upon the geometry considered)

q_0 = surcharge loading

Again the total cohesion can be expressed by the terms of Equation [2].

Depending upon the soil type and the geometry considered, the ultimate bearing capacity is computed from either the Broms approach or the Hanna and Meyerhof approach. Broms approach is used to compute the bearing capacity for Options 1, 2, and 4 as illustrated in Figures 3, 4, and 6. For soft clay subgrades, the Hanna and Meyerhof approach is used to compute the bearing capacity for the mechanism illustrated in Figure 5 and Option 3. (Usually the failure mechanism illustrated in Figure 5 would not be of concern for stronger subgrades.)

An interactive computer program called BEARING, was developed to prompt the user for the various elements of input data and to calculate the ultimate bearing capacity by either the Broms or the Hanna and Meyerhof approach. Utilization of the Broms approach results in an ultimate bearing capacity for the subgrade surface, whereas utilization of the Hanna and Meyerhof approach results in an ultimate bearing capacity for the combined ballast-subgrade system. A unique value for bearing capacity is computed for each geometry and failure mechanism considered.

Included in the final report are various charts which summarize typical bearing capacity values as a function of soil type and loading configuration. A typical example bearing capacity chart is illustrated in Figure 10.

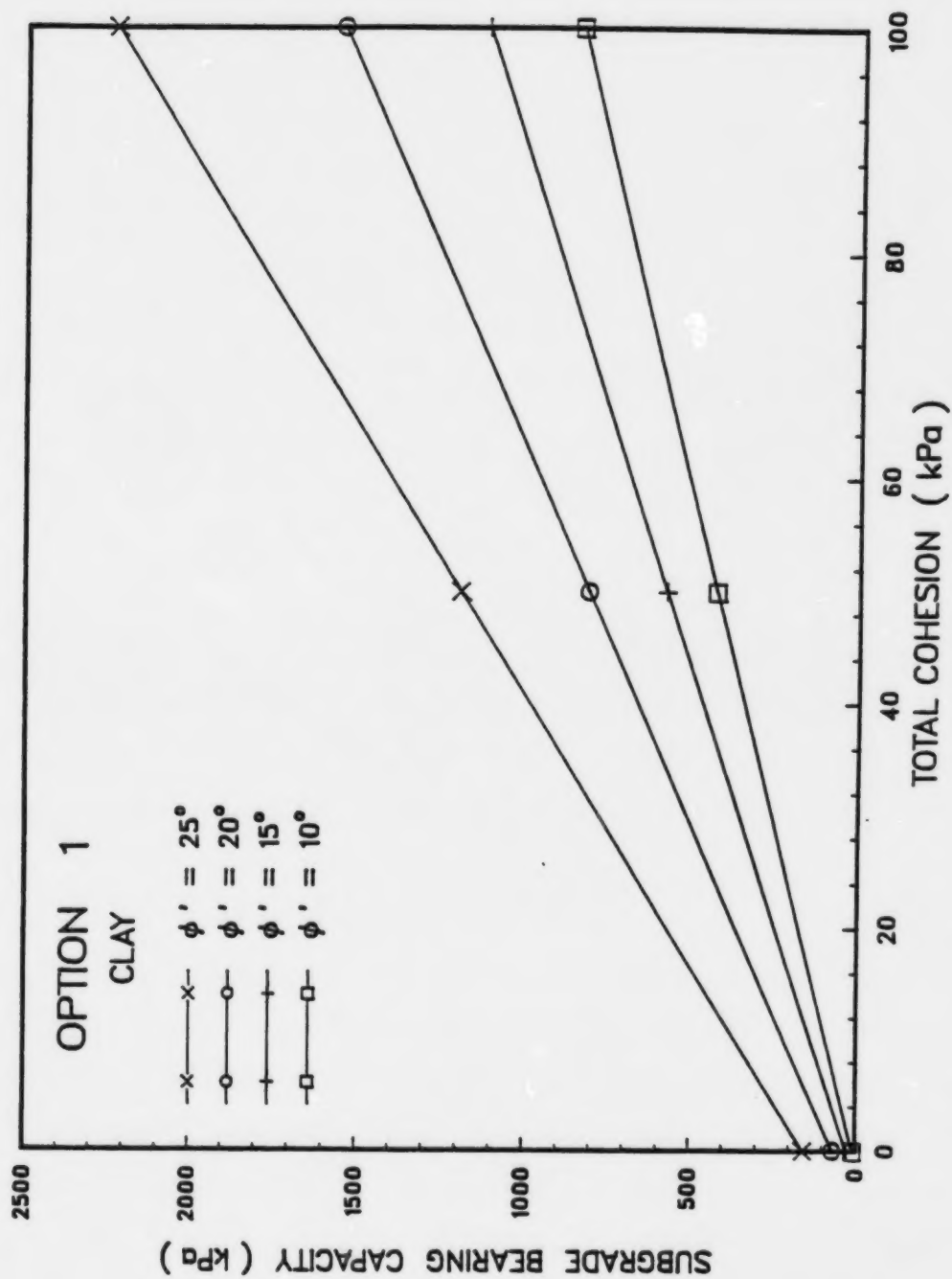


Fig. 10 Typical example of a bearing capacity versus total cohesion chart

The ultimate bearing capacity is then compared to an average stress which is representative of the stress distribution beneath the loaded structure.

4.2 The Prediction of the Average Stress Distribution

The prediction of the three-dimensional stress distribution is accomplished through the use of the GEOTRACK computer program. GEOTRACK is a commercially available computer package which provides a reasonable representation of the load transfer from the wheel of the train through the rails and ties and the ballast (4). Figure 11 illustrates how the rails are modelled as elastic beams supported by ties which are also represented as elastic beams. The GEOTRACK model emphasizes the geotechnical behaviour of the tie-track structure and therefore provides a reasonable representation of the soil layers. Each soil layer is characterized by a flexible plate with a stress-dependent modulus of elasticity and Poisson's ratio. A combination of the stiffness matrix of the tie-track structure with the stiffness matrix of the soil layers which are modelled as flexible plates is the essence of the computer model GEOTRACK.

Output from the GEOTRACK computer model includes the principal stresses, the equivalent triaxial stresses, and the vertical, horizontal and shear stresses. A post processing graphics package was developed for the GEOTRACK model for the purpose of plotting the output. Figures 12 and 13 show typical vertical stress output produced by the GEOTRACK model for a geometry perpendicular to the track (Figure 12) and for a geometry parallel to the track (Figure 13).

Included in the final report is a summary of the computer output

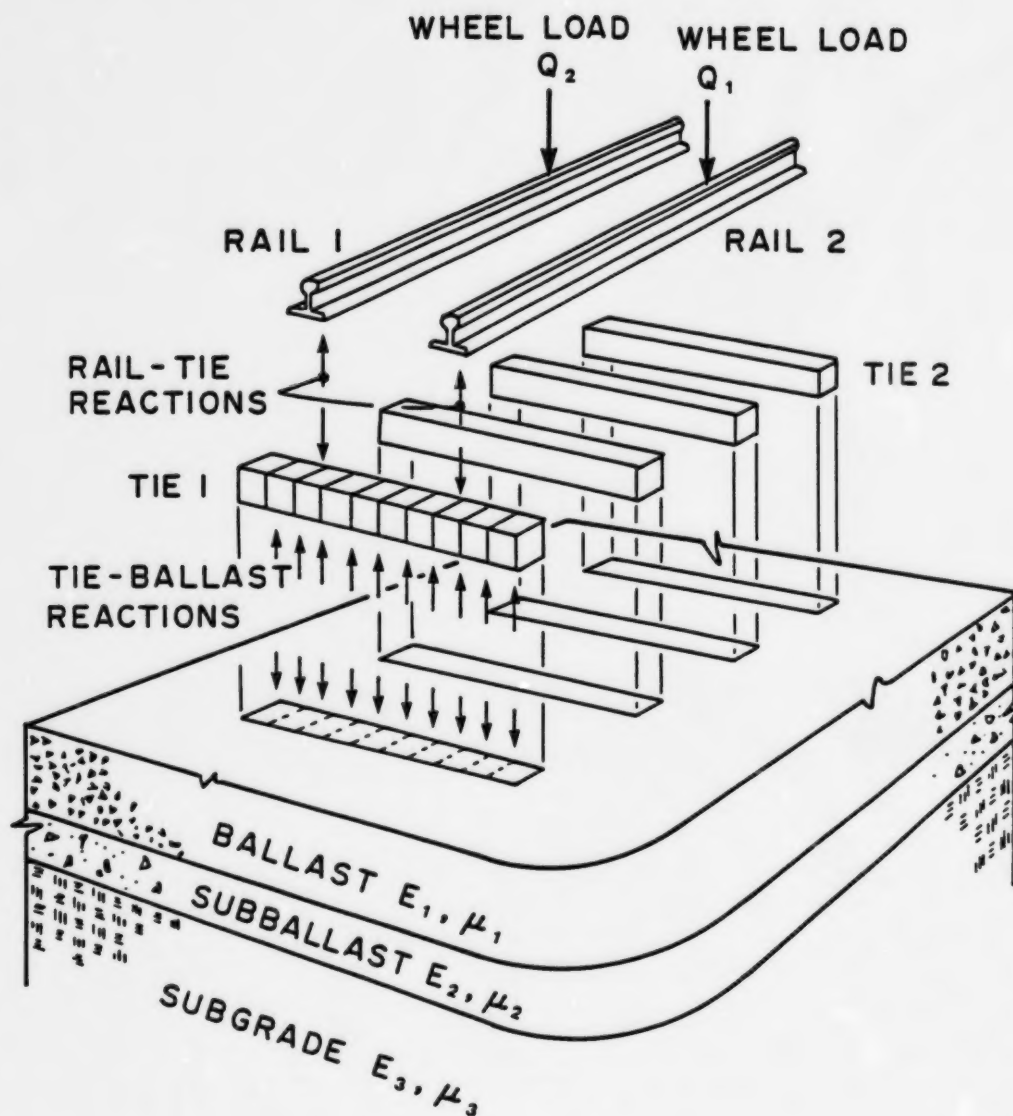


Fig. 11 Forces and elements in the GEOTRACK model

S-ZZ, INCREMENTAL STRESS IN VERTICAL DIRECTION (kPa)

FILE NAME E1035T36

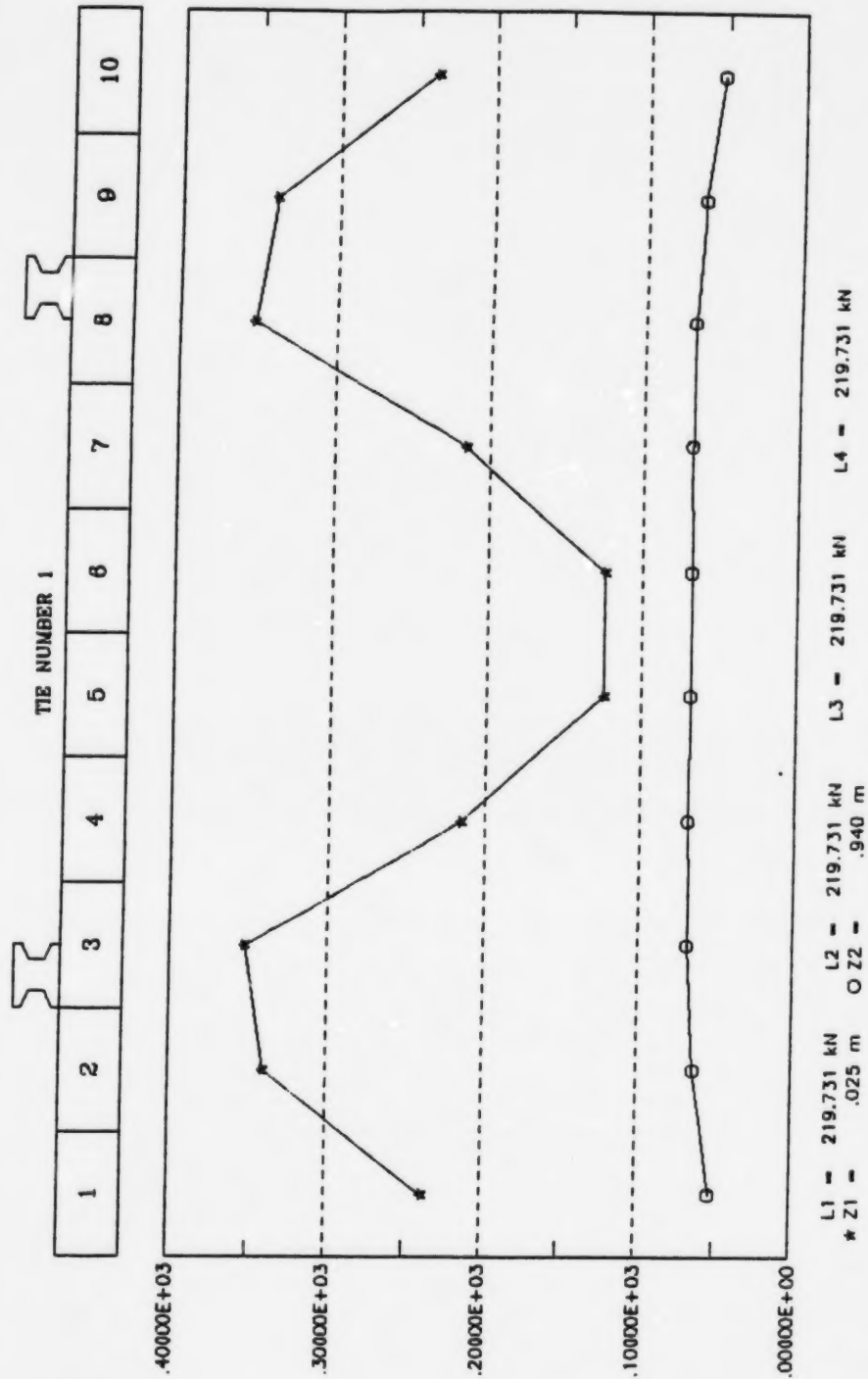


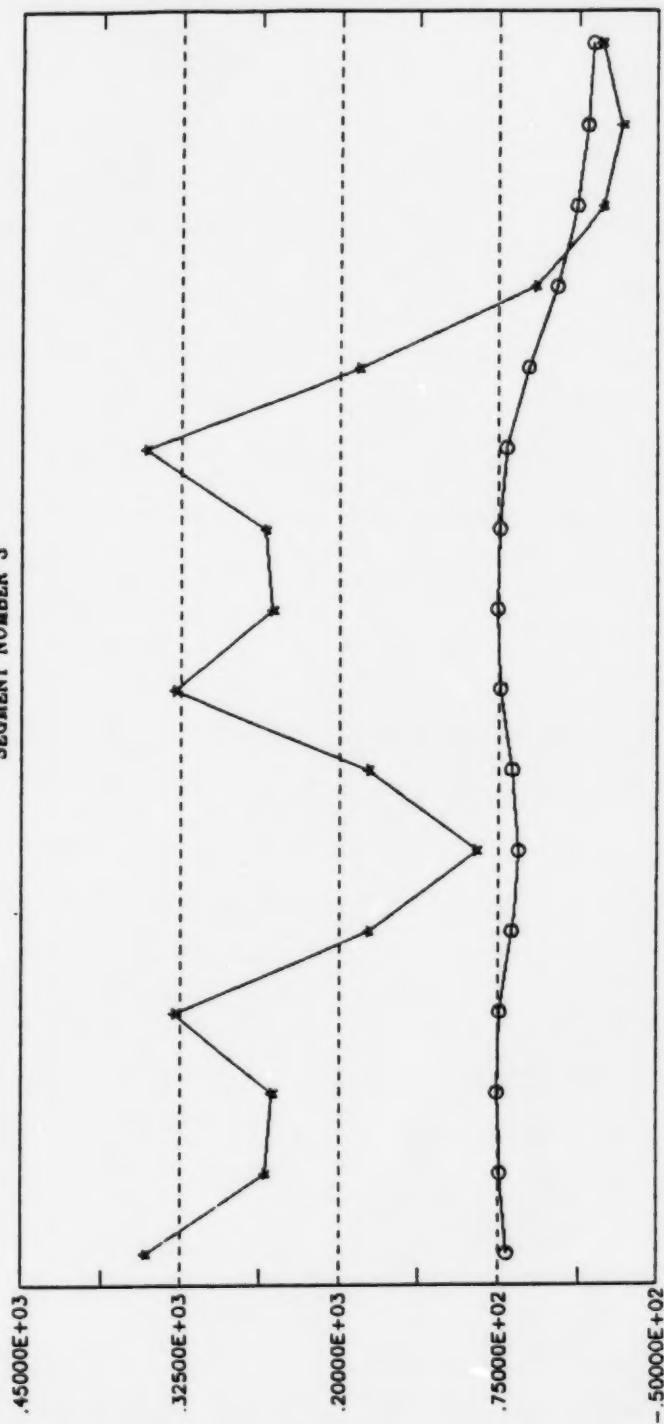
Fig. 12 Typical GEOTRACK vertical stress output for geometry perpendicular to the track

S-ZZ, INCREMENTAL STRESS IN VERTICAL DIRECTION (kPa)

FILE NAME E1035T38

▽		▽		▽		▽		▽		▽		▽		▽		▽	
L1		L2		L3		L4											
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

SEGMENT NUMBER 3



L1 = 219.731 kN L2 = 219.731 kN L3 = 219.731 kN L4 = 219.731 kN
 * Z1 = .025 m O Z2 = .940 m

Fig. 13 Typical GEOTRACK vertical stress output for geometry parallel to the track

detailing the subgrade or ballast surface stress as a function of the granular thickness below the tie for various loading configurations, soil parameters and axle loads. Figure 14 illustrates a typical stress chart as presented in the final report.

The ultimate bearing capacity estimate obtained from Section 4.1 results in a unique value which represents the subgrade bearing capacity for each of the three failure mechanisms considered by Broms approach. Alternately, a unique value of the combined ballast-subgrade bearing capacity is determined from the Hanna and Meyerhof approach. Consequently, the stress distribution must be reduced to a single value if the bearing capacity and the stress are to be compared. The stress distribution can be averaged to a single value for each of the bearing capacity options which are considered. This averaging is accomplished through another post-processing computer program, called STRESS.

Comparison of Broms (3) subgrade bearing capacity for the whole track and a view perpendicular to the track is accomplished by averaging the stress distribution beneath the whole track (Figure 15). Although a bearing capacity approach has been presented for Option 1, an Option 1 failure geometry is better analyzed using slope stability methods of analysis.

The stress distribution beneath $1/3$ of the tie length for each tie within the extent of a double truck load is averaged for the subgrade surface. The average stress computed in this manner is reserved for comparison to the Broms approach for the Option 2 geometry considered in Figure 4. The averaging procedure is shown schematically in Figure 16.

For comparison to the Hanna and Meyerhof (1) combined ballast-subgrade bearing capacity, the stress distribution beneath any

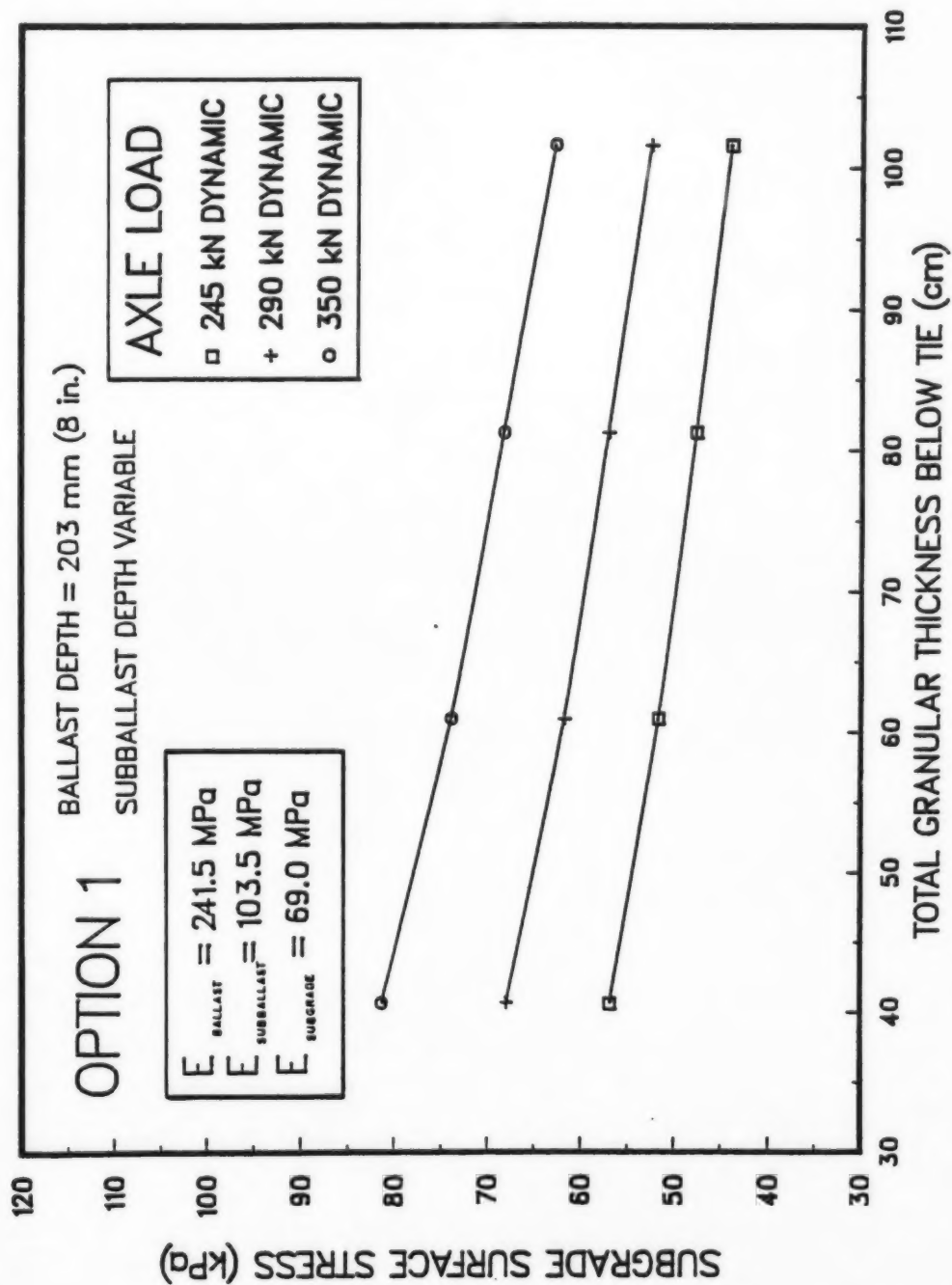
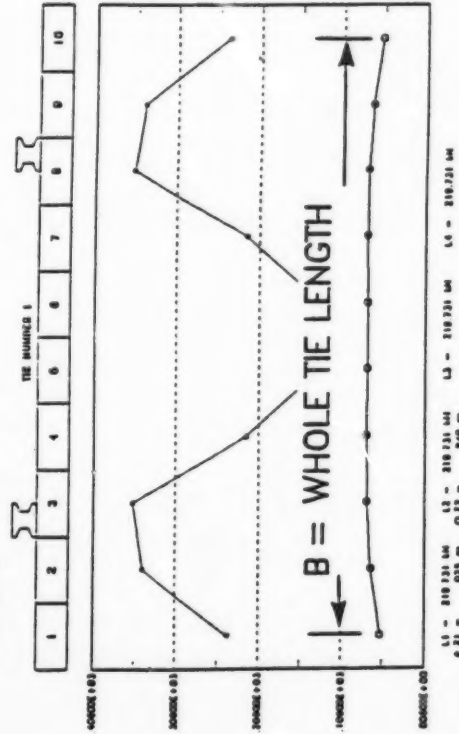
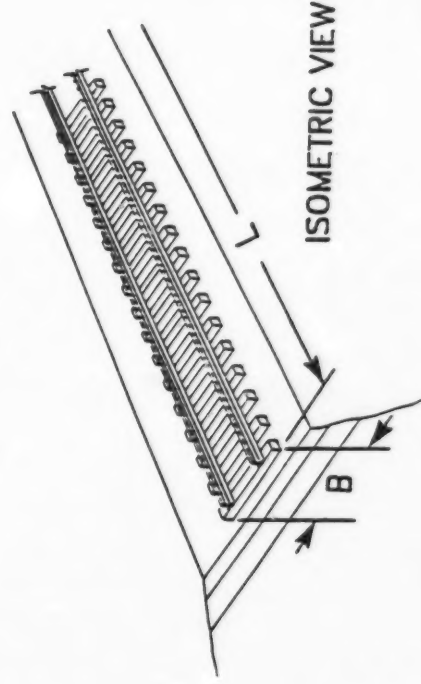


Fig. 14 Typical example of a subgrade surface stress versus granular thickness chart

S-ZZ, INCREMENTAL STRESS IN VERTICAL DIRECTION (kPa)



CROSS-SECTIONAL VIEW

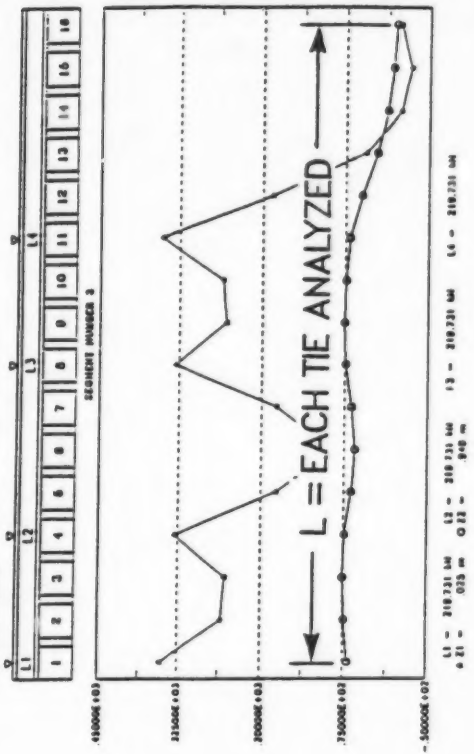


ISOMETRIC VIEW

OPTION 1

AVERAGE OF SUBGRADE SURFACE STRESSES
FOR WHOLE TIE LENGTH
FOR EACH TIE ANALYZED
ALONG LENGTH OF TRACK

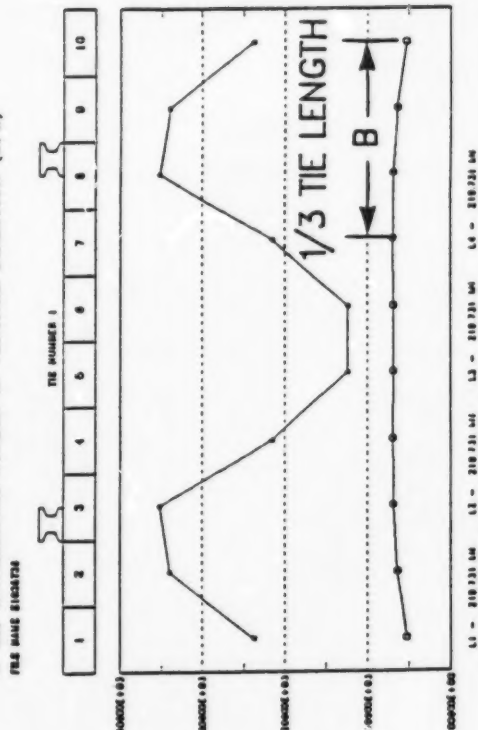
S-ZZ, INCREMENTAL STRESS IN VERTICAL DIRECTION (kPa)



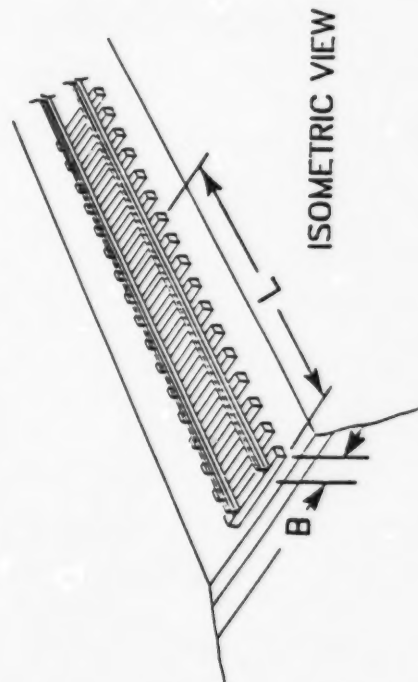
LONGITUDINAL VIEW

Fig. 15 Option 1: Average of the subgrade surface stress beneath the whole track

S-ZZ, INCREMENTAL STRESS IN VERTICAL DIRECTION (kPa)



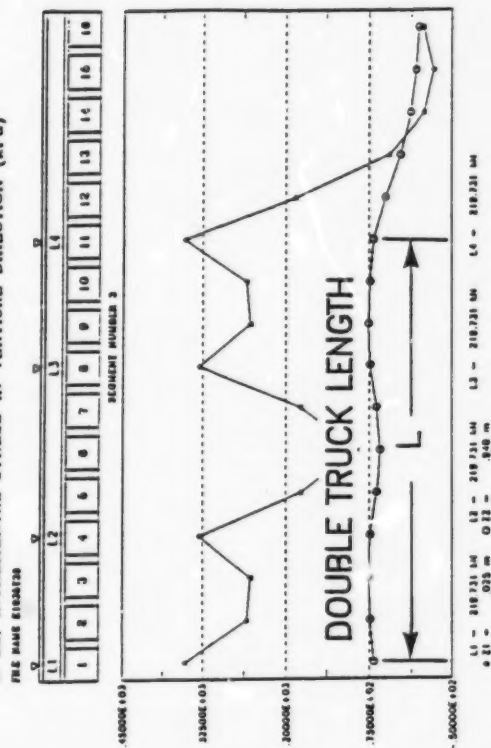
CROSS-SECTIONAL VIEW



OPTION 2

AVERAGE OF SUBGRADE SURFACE STRESSES
FOR 1/3 TIE LENGTH
FOR EACH TIE
WITHIN LENGTH OF DOUBLE TRUCK

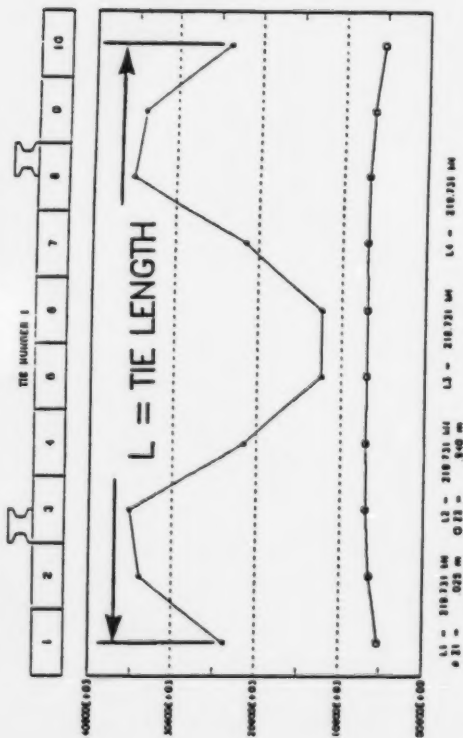
S-ZZ, INCREMENTAL STRESS IN VERTICAL DIRECTION (kPa)



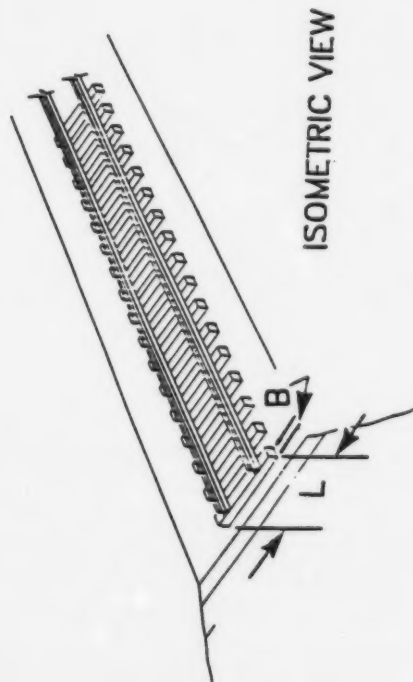
LONGITUDINAL VIEW

Fig. 16 Option 2: Average of the subgrade surface stress beneath 1/3 of the track and for double truck loading

S-ZZ, INCREMENTAL STRESS IN VERTICAL DIRECTION (kPa)
FILE NAME S18372M



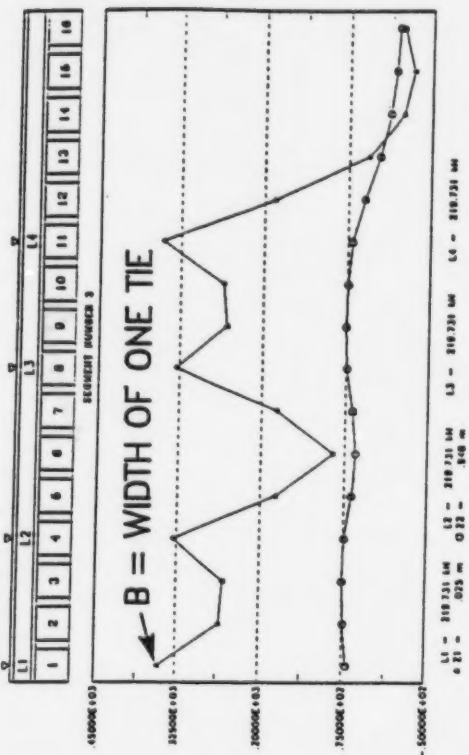
CROSS-SECTIONAL VIEW



OPTION 3

AVERAGE OF BALLAST SURFACE STRESSES
FOR WIDTH OF ONE TIE
AND LENGTH OF ONE TIE

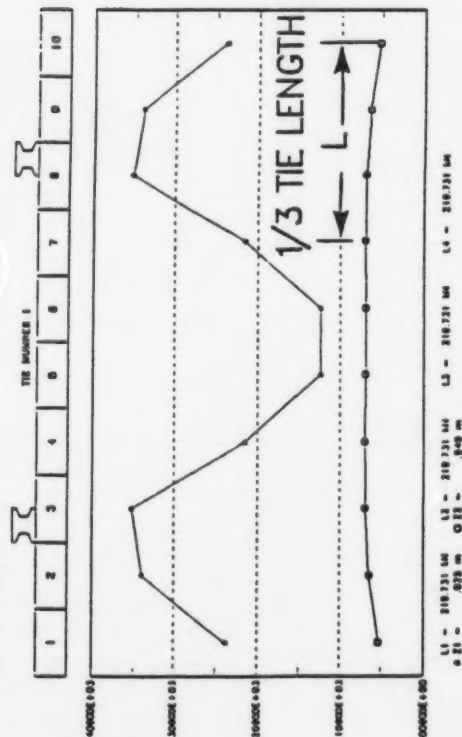
S-ZZ, INCREMENTAL STRESS IN VERTICAL DIRECTION (kPa)
FILE NAME S18372M



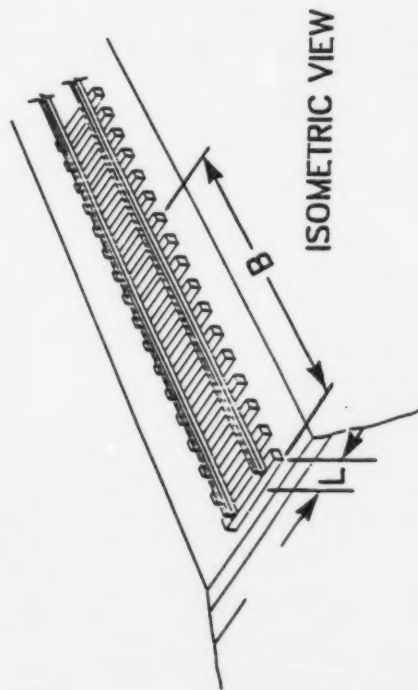
LONGITUDINAL VIEW

Fig. 17 Option 3: Average of the ballast surface stresses for comparison to the Hanna and Meyerhof bearing capacity approach

S-27, INCREMENTAL STRESS IN VERTICAL DIRECTION (kPa)



CROSS-SECTIONAL VIEW



OPTION 4

AVERAGE OF SUBGRADE SURFACE STRESSES
FOR WIDTH OF DOUBLE TRUCK
AND LENGTH OF 1/3 TIE

S-22, INCREMENTAL STRESS IN VERTICAL DIRECTION (kPa)

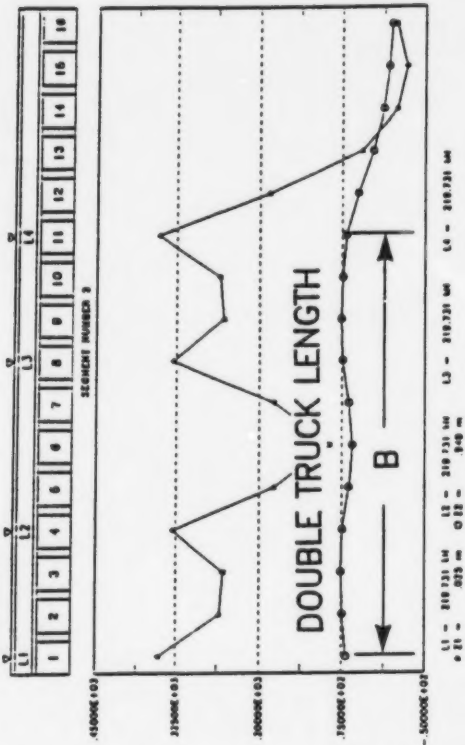


Fig. 18 Option 4: Average of the subgrade surface stress beneath 1/3 of the track and for double truck loading

individual tie is simply averaged at the ballast surface below an individual tie (Figure 17). This average is referred to by the Option 3 "Stress Averaging Technique" and is to be compared to Option 3 of the bearing capacity mechanisms.

The averaging procedure for the stress distribution beneath a double truck load and $1/3$ of the tie length is shown schematically in Figure 18. The Option 2 averaging procedure (Figure 16) and the Option 4 averaging procedure (Figure 18) produce the same results for the average stress distribution; however, the bearing capacities computed by the two options are quite different.

The resulting values from the averaging procedure are saved for comparison to the estimations of the bearing capacity.

4.3 Development of the Bearing Capacity Design Charts

A set of soil parameters and any one of the four failure geometries considered, produces a unique bearing capacity. Similarly, for a particular set of loading conditions and soil parameters, a single stress distribution beneath the tie-track structure is computed. The stress distribution can be averaged to produce an average stress corresponding to any one of the four failure geometries considered. The resulting bearing capacity is divided by the average stress to arrive at a bearing capacity factor of safety. The bearing capacity factor of safety is then a function of the loading conditions, soil parameters and the failure mechanism.

A computer program, COMPARE, was developed to read the STRESS output and the BEARING output and then compute a bearing capacity factor of safety.

5.0 RESULTS

A typical bearing capacity factor of safety chart is presented in Figure 19. The bearing capacity factors of safety are presented as a function of the thickness of granular material below the tie. The soil parameters for which the chart was developed are shown on each of the charts. The failure geometry and loading conditions to which the factors of safety apply are designated in the corner of the chart by the appropriate Option No. from Figures 3, 4, 5, and 6. A bearing capacity factor of safety greater than 1 does not imply that a bearing capacity failure could not occur. This results from the fact that the bearing capacity approach produces a single value to represent the strength of a heterogeneous subgrade system in which planes of weakness may exist. In addition, the choice of design values for the soil parameters, track structure, and loading configuration is subject to error which may be cumulative for each of the many design values which enter into the analysis. Conventional use of the bearing capacity equation for shallow footings requires the use of a bearing capacity factor of 3.0. Present research indicates that a bearing capacity factor of safety of 2.5 to 3.0 would be reasonable for use with the design charts presented for railway systems. However, further research is necessary to develop confidence in the use of a particular value for the bearing capacity factor of safety.

All of the design bearing capacity factor of safety charts developed, including charts of the average stress as a function of granular thickness and the bearing capacity as a function of the soil parameters, are presented in the final report. The charts are based on the properties of a few typical western Canadian soils.

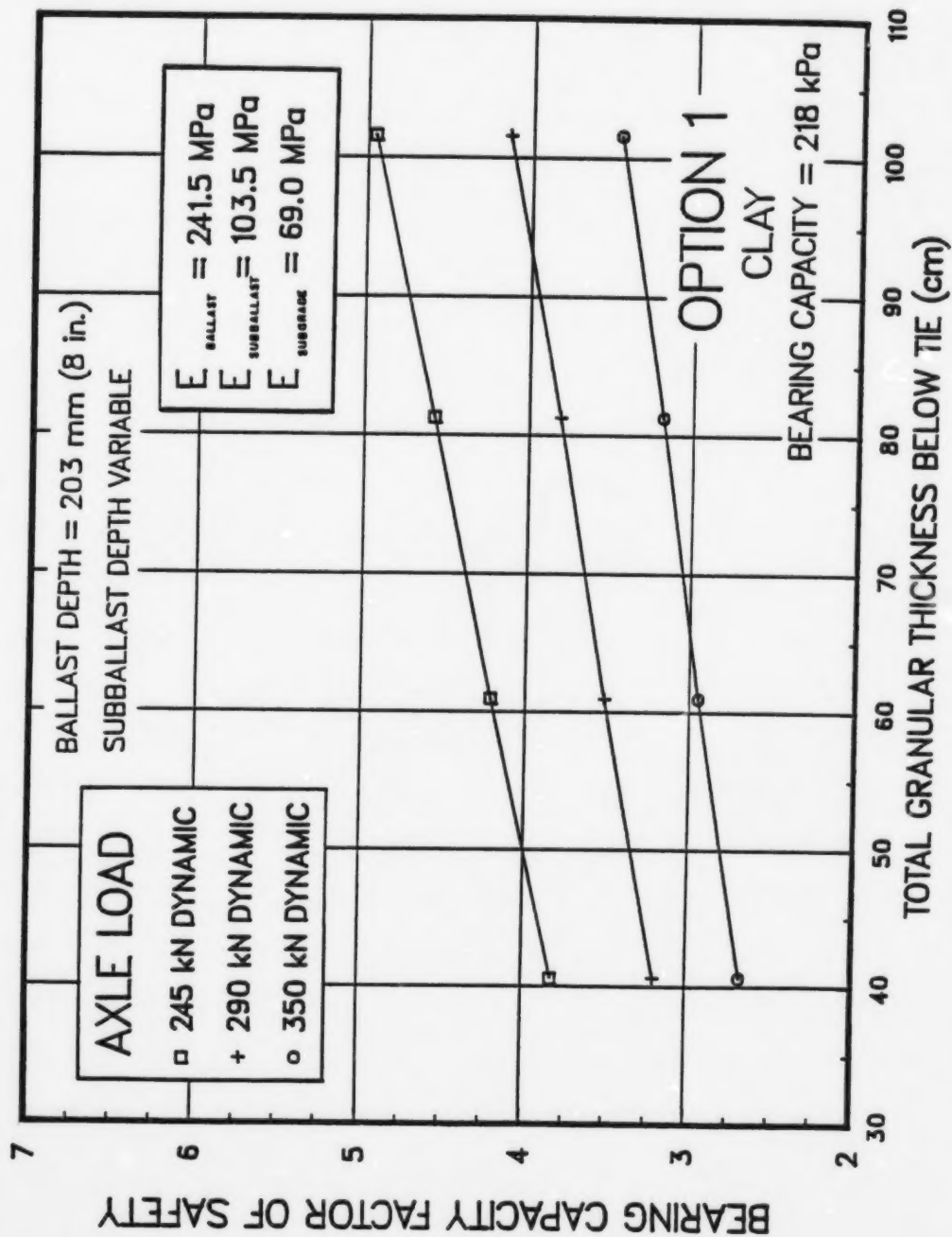


Fig. 19 Typical example of a bearing capacity factor of safety chart

6.0 CONCLUSIONS / RECOMMENDATIONS

A design procedure has been developed which can be used to predict the bearing capacity factor of safety for various axle loads, loading configurations and soil parameters. The user may choose to use the design charts or the user may choose to use the series of computer programs to compute the factor of safety against bearing capacity failure.

It is recommended that the user measure the relevant soil parameter values at a particular site. The design suction value should be either based on measurements or a reasonable estimate. Further research would be useful to determine reasonable estimates. The ϕ' and ϕ^b angles should be measured in the laboratory and the repeated loading moduli for the ballast and the subgrade should also be measured. Published values for the soil parameters can be used as a guide.

A bearing capacity factor of safety of 2.5 to 3.0 is recommended at this time. However, the value of the bearing capacity is dependent upon the soil and water content conditions at a site. Therefore, where the soil and water content conditions can be expected to be extremely variable, it is recommended to use a greater value for the bearing capacity factor of safety.

Inherent within the computer program GEOTRACK is the assumption that the soil layers act as plates which are infinite in lateral extent. Consequently, when the slope of the ballast-subballast subgrade system is large, error may be introduced into the computed stress distribution and hence the averaged stress. This inherent assumption must be taken into consideration when choosing an appropriate bearing capacity factor of safety. Further research, in the proposal stage, would provide an

estimate of the error involved and a means for circumventing the error.

Design of the railway ballast-subballast-subgrade system cannot be completed on the basis of a bearing capacity approach alone. It is essential that the user also analyze the embankments to ensure the stability of the overall slope. In addition, the final railway subgrade design must not exclude drainage requirements.

The bearing capacity charts should be used to complement existing design procedures. It is only through use that the design procedure which has been developed can be assessed for approval or modification. Use of the procedure will provide feedback on an appropriate bearing capacity factor of safety for design, information on the reliability of the stress calculations and the reliability of the soil suction parameters.

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2. Kraft, Leland M. and Helfrich, Steven C. (1983) Bearing capacity of shallow footing, sand over clay. Canadian Geotechnical Journal, Vol. 20, pp. 182 to 185.
3. Broms, Bengt B. (1965) Effect of degree of saturation on bearing capacity of flexible pavements. Presented at the 43rd Annual Meeting of the Committee on Flexible Pavement Design, Ithaca, New York.
4. Chang, C.S., Adegoke, C.W. and Selig, E.T. (1980) GEOTRACK model for railroad track performance. Journal of the Geotechnical Engineering Division, ASCE, Volume 106, pp. 1201 to 1218.